

# Pore geometry changes associated with the development of compaction bands in an analogue reservoir rock

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## Introduction

A number of important physical properties, such as elastic moduli, seismic velocity, compressibility, and various poro-elastic parameters (e.g., Skempton ratio, strength, failure behavior, electrical conductivity, and permeability) depend strongly on porosity. Predicting the effects of porosity on many physical parameters thus requires that the quantity, shape, and distribution of porosity be characterized accurately. Furthermore, in some geoscience applications of interest, processes such as mechanical deformation and permeability may be coupled, adding to their complexity. This investigation is focused on characterizing the change in pore geometry and flow properties associated with compactive deformation.

Tabular zones of uniaxial compaction with no shear offset, called compaction bands, have been observed in the field [1] and lab [2] and have been analyzed theoretically [3]. Conventional triaxial compression experiments with acoustic emission (AE) detection and location suggest the development of localized zones of intense deformation that initiate at sample ends and propagate uniformly through the specimen during testing [4, 5]. For a deformed sample, both visual observations of the sample surface and P-wave velocity measurements suggest deformation within a zone of localized compaction. Light optical and scanning electron microscopy (SEM) revealed a reduction in porosity accomplished in the absence of grain breakage prior to the development of compaction bands, followed by further reduction of porosity and severe grain comminution associated with the propagation of the compaction band [5].

The focus of this work is to extend the two-dimensional analysis to three dimensions using synchrotron computed microtomography (CMT). CMT offers a monochromatic high flux source of x-rays sufficient for relatively high spatial resolution ( $\sim 1\text{--}3\ \mu\text{m}$ ). This data will be compared with results obtained by laser scanning confocal microscopy (LSCM), which has superior resolution (to  $0.1\ \mu\text{m}$ ) but limited range normal to the imaging plane. The characterized volumes will be used for lattice Boltzmann (LB) numerical simulations of single phase flow on a massively parallel processor (MPP) platform [6].

## Methods and Materials

The rock used in this investigation, Castlegate sandstone, is an analog reservoir rock with weak cementation, fine to medium grain size ( $\sim 0.2\ \text{mm}$ ), and a bulk porosity of 28%.

Compressive triaxial testing was performed on cylindrical cores ( $50.8 \times 127\ \text{mm}$ ) taken parallel to bedding.

After testing, the sample was impregnated with a fluoro-chrome-doped low-viscosity epoxy. The epoxy allowed for localized extraction of smaller cores ( $25.4\ \text{mm}$ ) that were used to prepare thin and thick sections. Very small cores ( $5\ \text{mm}$ ) were also extracted and centerless ground to  $2\ \text{mm}$  diameter for use in the synchrotron experiments.

CMT experiments were performed at the Advanced Photon Source bending magnet beamline 13-BM, operated by GSECARS in collaboration with Dr. M.L. Rivers. The white x-ray beam was diffracted horizontally through a channel cut Si(220) monochromator yielding a focused beam with energy of  $16.9\ \text{keV}$ . The  $2\ \text{mm}$  cores were placed in the path of the focused beam, which projected onto a single-crystal YAG scintillator and reflected into a microscope objective connected to a  $1300 \times 1200$  pixel fast CCD detector. Spatial resolution varied between  $1.6$  and  $3.3\ \mu\text{m}/\text{voxel}$ .

Reconstruction was performed with software written in IDL®, generating reconstructed data sets of  $661 \times 661 \times 517$  and  $1327 \times 1327 \times 920$  for the low- and high-resolution data, respectively. The data were saved as eight-bit binary unsigned characters. The data were visualized with commercial volume rendering software (Voxel View ®).

## Results and Discussion

Previously recorded SEM images from the untested and deformed specimens are shown in Fig. 1. The untested Castlegate [Fig. 1(a)] contains subangular to subrounded grains with a high number of point and tangential contacts and well-connected porosity. In Fig. 1(b), in the region ahead of the compaction band, porosity was reduced, which was also corroborated by stereological measurement [5], but the grains remained largely intact. After the propagation of the compaction band, porosity was reduced further and associated with severe grain fracture [Fig. 1(c)].

Fig. 2 shows subvolumes from the larger tomographic data sets for the untested (a) and deformed rock samples (b, c). The images represent 100–150 slices of data and are  $1.3\ \text{mm}$  square by  $136\ \mu\text{m}$  (a),  $97\ \mu\text{m}$  (b), and  $146\ \mu\text{m}$  (c) in the vertical dimension. In Fig. 2(a) grains and porosity are well defined, consistent with Fig. 1(a). Similarly, the grains of the mildly deformed region are still undamaged and bulk porosity appears reduced [Fig. 1 and 2(b)]. The current

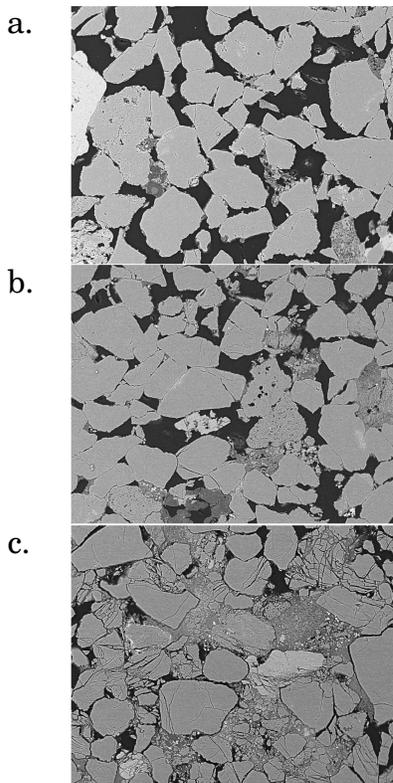


Figure 1: SEM images of polished thick sections. (a) Untested Castlegate showing large pore size and high bulk porosity. (b) Reduction of porosity in deformation zone preceding the formation of a compaction band. Note that the grains remain largely unfractured. (c) Deformation in compaction band with substantial reduction in porosity and grain microfracture. The width of the images is 1 mm. Compaction direction is horizontal in (b) and (c).

tomography resolution is not capable of resolving the fine scale detail observed in Fig. 1(c), but bulk porosity is noticeably reduced in Fig. 2(c). It is expected that the significant reduction of porosity evident in Fig. 2(b, c) will be reflected in the flow simulations.

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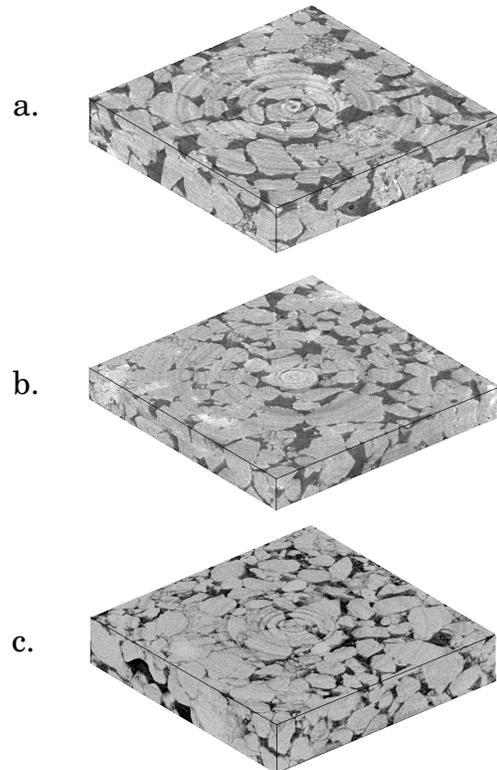


Figure 2: Reconstructed subvolumes from CMT. (a) Untested Castlegate. (b) Region ahead of compaction band with reduced porosity and maintained grain integrity. (c) Further compactive deformation with reduced porosity. The detailed microfractures of Fig. 1(c) are not resolved. All volumes are 1.3 mm square by 136  $\mu\text{m}$  (a), 97  $\mu\text{m}$  (b), and 146  $\mu\text{m}$  (c) in the vertical dimension.

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